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# (54) BLOOD OXYGENATOR

(71) We, THE UNIVERSITY OF STRATHCLYDE, a British University incorporated by Royal Charter, of 204 George Street, Glasgow G1 1XW, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a blood oxygenator.

Artificial lungs incorporating a gas-permeable membrane between the blood and the gas are capable of prolonged cardiopulmonary support with minimal blood damage. If the blood flow is laminar and rectilinear (as in the majority of membrane units presently available) then the artificial lung performance is limited, not by the membrane permeablility, but by gas diffusion in the blood. It is well known that the convective mixing in the blood phase greatly improves the performance. Although turbulent blood flow would be a very effective form of mixing, severe blood trauma would result. Consequently some kind to laminar mixing is necessary to minimise trauma.

According to the present invention there is provided a blood oxygenator comprising a pair of cylinders, one within the other defining a space therebetween, an oxygen permeable membrane fixed to each of the opposed cylinder walls within the space to form between the membranes a flow [illegible] for blood and between each [illegible] rotating at least one of the cylinders

When a liquid is made to flow axially through an annular space between two cylinders placed one inside the other and at least one of the cylinders is rotated, the flow pattern which develops depends on a number of factors. The axial Reynolds number R is defined as $Vd/\nu$ where V is the average axial velocity, d is the annular gap and $\nu$ is the kinematic viscosity of the liquid. The Taylor number T is defined as $\Omega^2 r_i d^3/\nu^2$ where $\Omega$ is the angular velocity of the cylinder, $r_i$ is the radius of the inner cylinder and d and $\nu$ are as defined above.

If the axial Reynolds number is zero, 4 major regimes may be identified:— (1) For low Taylor numbers the flow is pure shear and of a Couette Type. (2) At a critical Taylor number, $T_c$, secondary toroidal laminar circulations develop, the strength of these secondary circulations increasing as the Taylor number increases above this critical value until a second critical value is reached. (3) When this latter critical value is exceeded, the secondary flow consists of toroidal vortices with superposed turbulence, and (4) When the Taylor number is increased still further, the toroidal vortices disappear and the flow is turbulent.

The second regime is the one of interest in the present invention. This regime is useful because it possesses secondary transverse laminar mixing and the strength of these circulations can be controlled by adjusting the angular velocity of the inner cylinder.

The oxygenator may include a gas-penetrable membrane support member located between each of the cylinder walls and the adjacent membrane so as to hold the membrane in spaced relationship to the walls.

The annular spaces between the inner cylinder and its adjacent membrane and between the outer cylinder and its adjacent membrane provide flowpaths for oxygen [illegible] therethrough.

The membrane support member may be of porous plastics material such as a reticular polyurethane foam, or it may have the form of a net or plastics material or it may be simply projections extending outwards from the cylinder wall, which projections hold the membrane in spaced relationship to the wall.

The membrane may be adhered to the

24. The central pipe 14 is connected to suitable rotary drive means indicated by 28 in the drawing.

Annular sealing means 29 are located around the central pipe 14 to seal the space between inner cylinder base plate 12 and base plate 24. It is made of rubber or resilient plastics material.

The central port 25 in base plate 24 has bearing means 33 for the pipe 14.

The membraneous sheets 5 and 7 are secured to the exposed faces of support members 4 and 6 by use of an adhesive or by heat sealing.

The oxygenator 1 sits upon a mounting bench 30 and is supported by a number (conveniently four) of support pillars 31 which engage recesses in the bench 30 and corresponding recesses in the base plate 24. The bench 30 has an aperture 32 for passage of oxygen inlet and outlet pipes 14 and 15 therethrough.

Locating members 34 are provided within the pipe 14 to lock the pipe 15 to pipe 14 so that it will rotate therewith. The members 34 are small plugs of plastics material having a central hole for receiving pipe 15 and several through-passages to permit outflow of oxygen through pipe 14.

Fig. 3 is the same section as Fig. 2 and all the reference numerals correspond, but it shows the relative positions of the cylinders 2 and 3 required to produce a flow-inducing arrangement. The centre O of inner cylinder 3 is offset from the centre X of outer cylinder 2. When cylinder 2 is rotated about an axis which passes through centre X the cylinder 3 rolls around the inner surface of outer cylinder 2 in a flow-inducing action. This action may implement or even replace any external blood pump used for pumping blood from the patient to the apparatus.

In use, blood is fed from a patient's vein through the tangential inlet 27 into the blood flow channel 8 defined between the membranes 5 and 7 whence it flows axially upwards into the space 23 defined between the outer conical-section closure member 21 and the inner conical end cap 11. Blood flows out of the oxygenator via the outlet 22 at the apex of the conical-section closure

[illegible] oxygen flows [illegible] the outer cylinder 2, and through the pipe 15 which extends coaxially through the central pipe 14 in the circular end plate 12 of the inner cylinder 3. From the circumferential inlet 19 oxygen flows axially downward through the support member 4 on the outer cylinder [illegible] that leaves the apparatus via the openings 20 in the cylinder wall 2. From the coaxial pipe 15 the oxygen flows via the circumferential port 16 into the reticular support 6 on the inner cylinder 3, axially downwards through the support 6 whence it flows inwardly through the ports 17 into the interior of cylinder 3 and leaves the apparatus through central pipe 14.

The inner cylinder 3 is rotated by the drive means 28. The flow rate of blood and the angular velocity of the cylinder are selected according to the theoretical considerations described hereinbefore to induce in the flow secondary currents in the form of vortices. The vortices promote mixing of the blood in the flow channel 8 thereby promoting oxygenation thereof on the surfaces of the membranes 5 and 7 through which oxygen permeates from the oxygen passing through the porous support members 4 and 6.

WHAT WE CLAIM IS:—

1. A blood oxygenator comprising a pair of cylinders, one within the other defining a space therebetween, an oxygen permeable membrane fixed to each of the opposed cylinder walls within the space to form between the membranes a flow channel for blood and between each membrane and adjacent cylinder wall a flow path for oxygen, inlet and outlet means for blood and for oxygen and drive means for rotating at least one of the cylinders.

2. An oxygenator according to claim 1. comprising also gas-penetrable support member interposed between each oxygen-permeable membrane and cylinder wall to hold the membrane in spaced relationship from the wall.

3. An oxygenator according to claim 2, in which the gas-penetrable support member is made of a foamed plastics material.

4. An oxygenator according to claim 1, or 2 or 3, in which the inner cylinder is a hollow cylinder closed at one end and having an end plate at the opposite end provided with a vent-pipe and including a circumferential gas inlet near one end and communicating with the oxygen flowpath located between the inner cylinder and the membrane, pipework for supply of oxygen to said inlet and extending from said inlet for connection to an external oxygen

[illegible] cylinder

5. An oxygenator according to any preceding claim, including a base plate providing a seat for one end of the outer cylinder, a closure plate at the opposite end of the outer cylinder and having a blood outlet located therein and being spaced from the inner cylinder end-plate to permit outflow of blood from the blood flowpath formed between the membranes, and in which a circumferential blood inlet is

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1480406 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

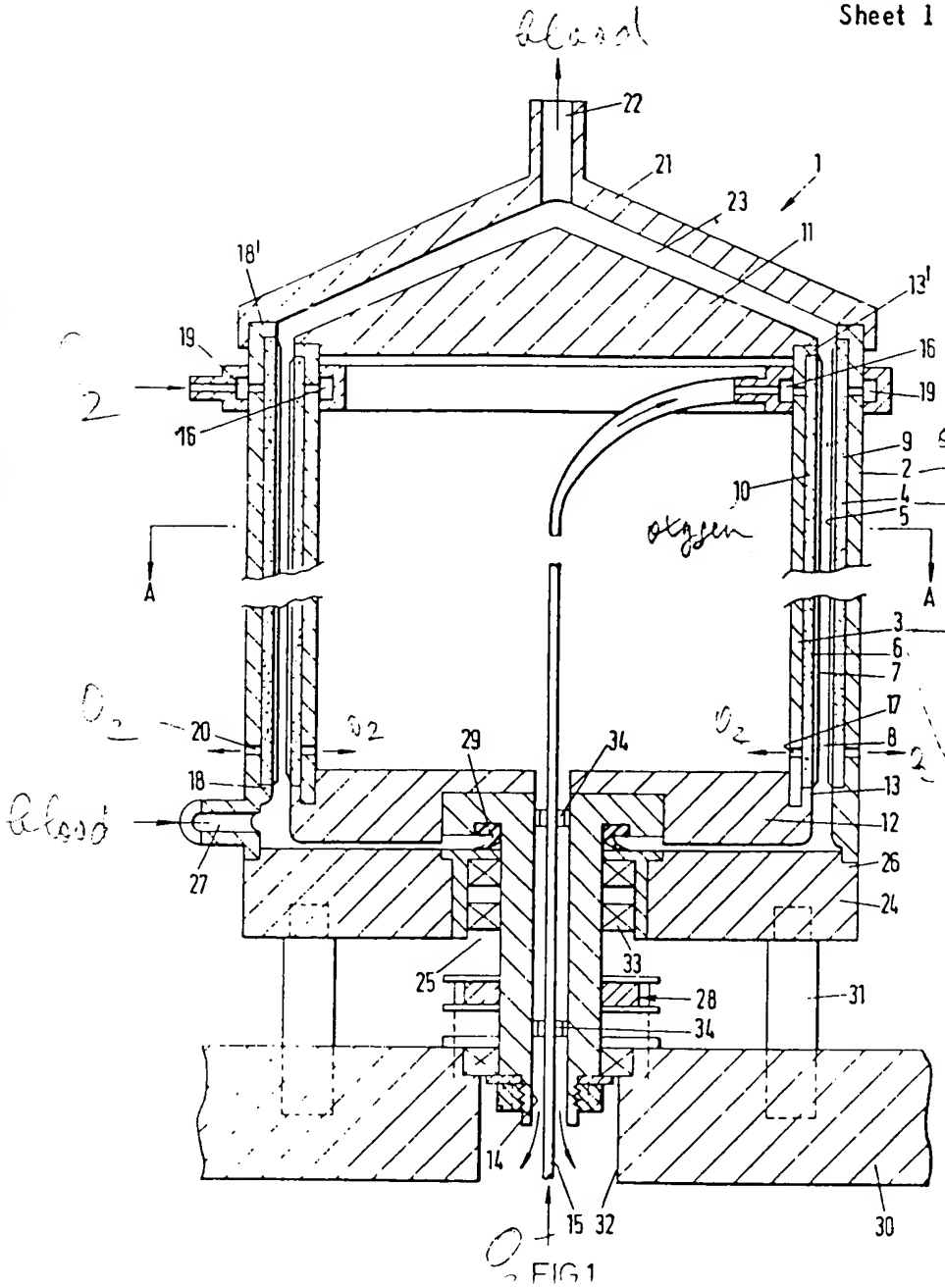


FIG 1

1480406 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

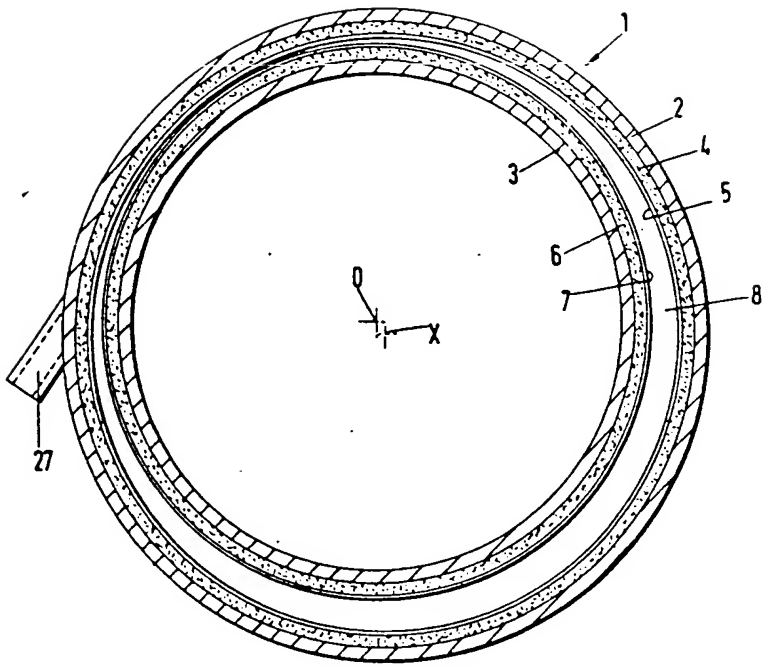


FIG. 3